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U.S. AIR FORCE

Project RAND

RECOMMENDATION

TO THE AIR STAFF

AN EARLIER RECONNAISSANCE SATELLITE SYSTEM (S)

12 NOVEMBER 1957

The RAND Corporation
SANTA MONICA • CALIFORNIA

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The RAND Corporation
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1700 MAIN ST. • SANTA MONICA • CALIFORNIA

12 November 1957

Deputy Chief of Staff, Development
Headquarters, United States Air Force
Washington 25, D. C.

SUBJECT: AN EARLIER RECONNAISSANCE SATELLITE SYSTEM

In the light of recent events, RAND has reviewed national and military intelligence problems, existing and proposed reconnaissance systems, and in particular, the current USAF satellite reconnaissance program (WS 117L). As a result of certain technical and conceptual breakthroughs, it is concluded that efficient satellite reconnaissance systems of considerable military worth can be obtained earlier and more easily than those envisioned in the current 117L program.

The systems proposed in this recommendation differ substantially from the current 117L system concept.

- The proposed systems use a spin-stabilized payload stage.
- They use a transverse panoramic camera of essentially conventional design, fixed to spin with the final stage, which scans across the line of flight.
- Either the entire payload or the film is recovered.

The first of the proposed systems uses a 12-inch camera, carrying 500 feet of 5-inch wide film. The extremely short exposure time--1/4000 sec--eliminates the need of attaining a precise altitude, exact image speed synchronization, difficult performance characteristics, and related problems. It will provide sharp photographs of about 60-ft ground resolution. Each exposure, covering some 300 miles across the line of flight, will photograph some 18,000 sq mi. The 500-ft roll will cover some 4,000,000 sq mi (almost half the S.U.) and show major targets, airfields, lines of communication, and urban and industrial areas. This satellite could weigh about 300 lb and be placed in a polar orbit at 180 ± 35 miles altitude by a combination of rockets such as Thor plus second stage Vanguard plus a third stage small solid rocket similar to the Vanguard's third stage. A one-day operation is envisaged, with recovery by command firing of a braking rocket on the 16th pass, so as to impact in a predictable ocean area.

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The next, more sophisticated, system would use a 36-inch camera, carry much more film, do more detailed reconnaissance--with a ground resolution of about 20 feet. This system can possibly be Thor boosted.

A third system--undoubtedly requiring Atlas-type boosting--would use a 120-inch camera and would have very large film capacity. This system will be able to accomplish very high quality photo reconnaissance and, most important, will do it better than any Air Force system now in development or in prospect will be able to do in the 1960's.

The earliest and simplest of the several systems will collect at least as much information in its one-day operation as the "early" 117L vehicle will in its useful life.

Because of our belief that the first system could be available about a year from start of work, the second in less than two years, and the third in about three years, we recommend that the U. S. Air Force begin work immediately to accomplish this program.

Success of this type of system should result in refocus of the present components of the 117L program to those tasks requiring the communication link and cyclic talk-back facility of 117L--warning, and daily surveillance of selected targets, being the principal high priority tasks requiring such an operation. Thus this new family of satellites and the type of satellite at present scheduled under 117L program would be mutually complementary and not competitive.

Descriptive diagrams and more detailed discussion of the proposed system are contained in the attached appendix. A RAND Research Memorandum, RM-2012, is also available.

RAND is actively engaged in further and more detailed studies supporting these proposals and will help in every way possible with the fulfillment of these objectives.

Yours very truly,

F. R. Collbohn

F. R. Collbohn

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AN EARLY RECONNAISSANCE SATELLITE SYSTEM

This appendix describes a reconnaissance satellite system that would be relatively simple in operation, would be available quickly as compared with the current 117L program, and would serve an extremely useful military purpose. The system would use a camera of essentially conventional design in a relatively unsophisticated orbiting vehicle. A launching date about one year from the date of contract is contemplated. The system will produce pictures of a scale and resolution that will yield valuable intelligence information about large areas of the Soviet Union.

1. RECONNAISSANCE: NEEDS AND MEANS

The need for better military intelligence on the USSR is acknowledged and aerial photographic reconnaissance is certainly a preferred means. For one thing, the area occupied by the Soviet Union and its political satellites is very large and, for the most part, inaccessible except by overflight. Secondly, in the immediate future it will be vital for us to know a great deal about the patterns of use. installation, and concealment of Soviet ICBM's. Finally, it is essential that we have detailed information from time to time on aircraft-missile phasing in the Soviet Union. We must know the character and composition of these major threats to our lives and security.

In describing airborne photographic reconnaissance systems, it is convenient, by way of developing an operational concept, to think in terms of four levels of reconnaissance: A, B. C. and D.

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Level A provides large-area search, measured in millions of square miles. Level B is limited-area search, measured in hundreds of thousands of square miles. Level C, specific-point-objective photography, is measured in hundreds of square miles. And Level D, technical-intelligence-objective photography, provides coverage in blocks tens of square miles or less in size.

The reconnaissance satellite system proposed permits us to progress systematically from Level A toward Level D in a series of system improvements. It will first enable us to cover millions of square miles of the Soviet Union giving us photographs of such a scale and resolution that significant intelligence information can be obtained. Such missions can be repeated from time to time to reveal new developments in the Soviet posture. Reconnaissance at Level A will also be valuable in providing information on where to conduct more detailed reconnaissance. While the system will not provide us with warning intelligence, it will help us estimate Soviet capabilities and identify certain kinds of major targets.

2. THE CAMERA

The camera proposed for this system is a transverse panoramic camera containing a 12 in. focal-length, highly corrected f/3.5 lens which covers a fairly narrow angle of approximately 20 degrees. Wide-angle scanning is accomplished by the expedient of moving the lens across the field during the exposure time.

For transverse scanning of the ground from a satellite, the camera must rotate around the longitudinal axis of the vehicle. For this application it is proposed to rotate the entire payload stage with the camera firmly attached, thus generating a sweep across the line of flight.

It is not proposed to rotate the camera within its carrier.

Figures 1a and 1b show the geometry of the camera, lens, and focal plane relationships. The lens is mounted perpendicular to the carrier's roll axis behind a quartz window in the surface of the carrier. The lens images the ground on a fixed slit in front of the focal plane, the slit serving, in effect, as a very fast shutter. When the film is moved during the scan exposure, at a rate exactly matching the image motion produced by passage of the carrier over the ground, a continous, sharp photograph is produced in the focal plane. During the portion of the rotational period in which the lens does not 'see' the ground, the slit is capped and a measured length of film is rolled off the supply spool in readiness for the next exposure. At the same time, the last exposure is wound up on the take-up spool.

Note that the transverse panoramic camera under discussion does not require the usual kind of attitude stabilization necessary for cameras mounted in aircraft. The entire carrier rotates; this is an important distinction between this proposal and other proposals for camera-carrying satellites.

Spin is imparted to the payload stage to produce the scan necessary for producing photographs across the line of flight. In addition, spin imparted to the payload stage stabilizes it in inertial space. That is, spin stabilization serves the twofold purpose of stabilizing the attitude of the camera in space and scanning the ground at the proper rate.

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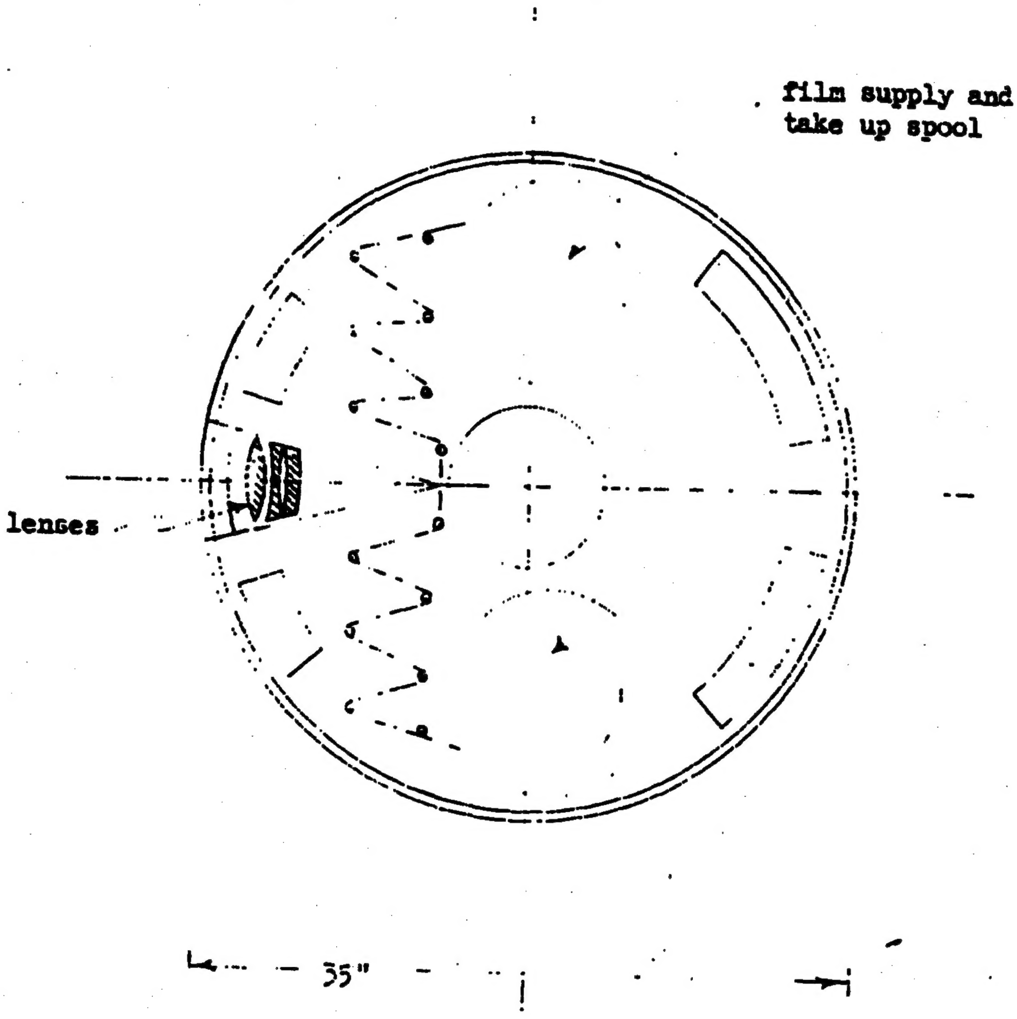

Fig. 1a Camera Geometry

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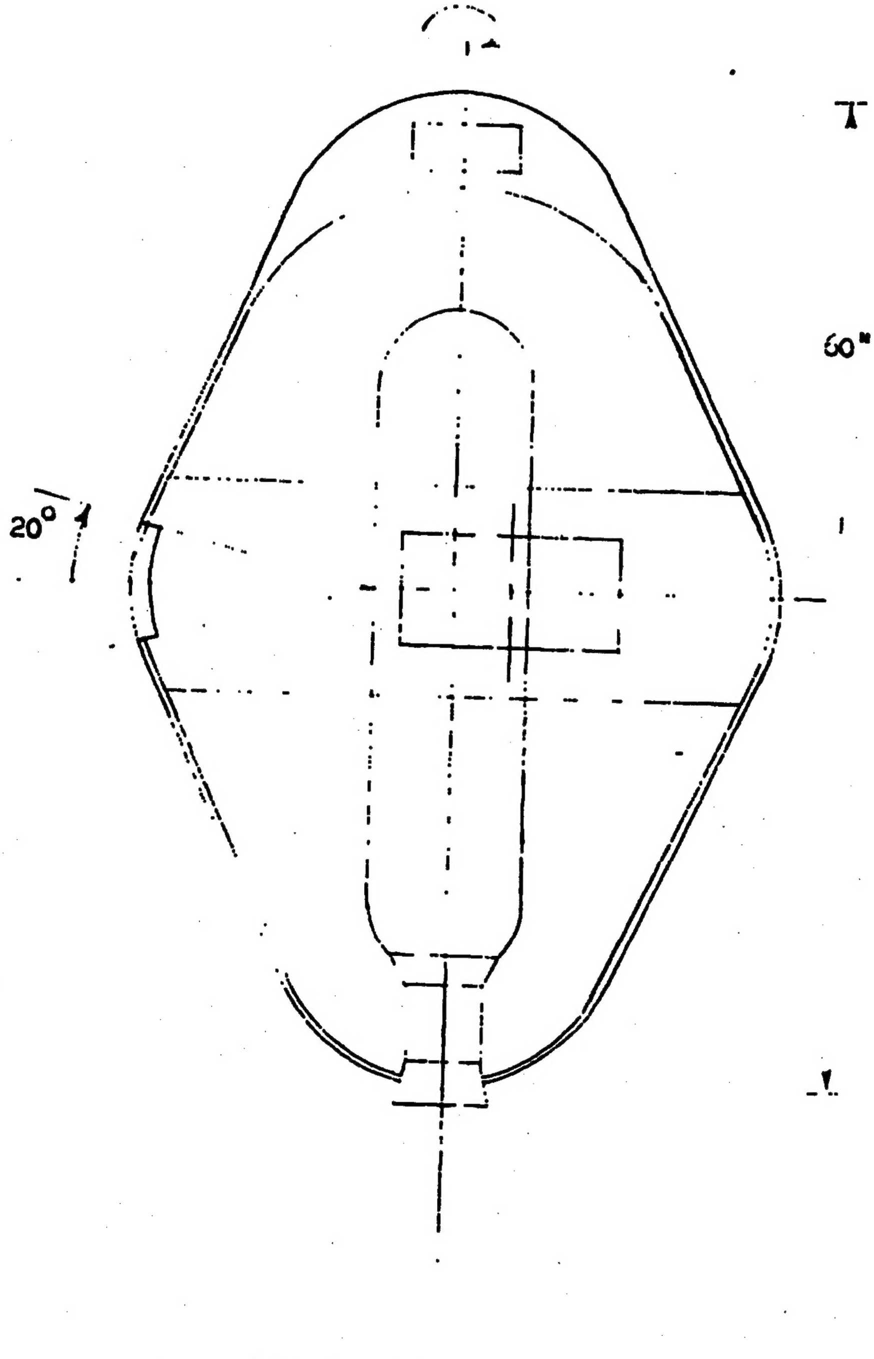

Fig. 1b Camera Geometry

The proper stabilized attitude of the camera in space is determined by the geography of the area to be surveyed (see Fig. 2). The tremendous area occupied by the Soviet Union and its political satellites has its major axis in longitude; that is, the area is stretched out in longitude and compressed in latitude. Most of the territory we are interested in, from a reconnaissance standpoint, lies between 40 degrees North and 70 degrees North. This fact turns out to be very fortunate as regards attitude stabilization, for it means that if the payload vehicle can be stabilized in an attitude horizontal to the surface of the earth at 55 degrees North—i.e., midway between the two latitudes—the camera will produce acceptable pictures over the entire distance from 40 degrees North to 70 degrees North. (The satellite is considered to be on a polar orbit, as will be discussed below.) Note from Fig. 2 that, when the payload stage is at 40 degrees North, the vertical, with respect to the long axis of the vehicle, is pointing back 15 degrees with respect to the earth; at 70 degrees North, it points forward 15 degrees. These angles result in very small errors in uncompensated image speed. These errors can be completely disregarded in the photography, as discussed below.

Another important feature of the camera lies in the employment of a very high effective shutter speed, or short exposure time. This allows us to ignore fairly substantial changes in altitude and uncompensated image speed, changes in vehicle velocity over the surface of the earth, small angular rates and displacements, and other such effects which, in any customary reconnaissance vehicle, would certainly ruin photographic quality.

It appears, at first sight, that taking photographs from a satellite moving at about 18,000 miles per hour would be an extraordinarily difficult

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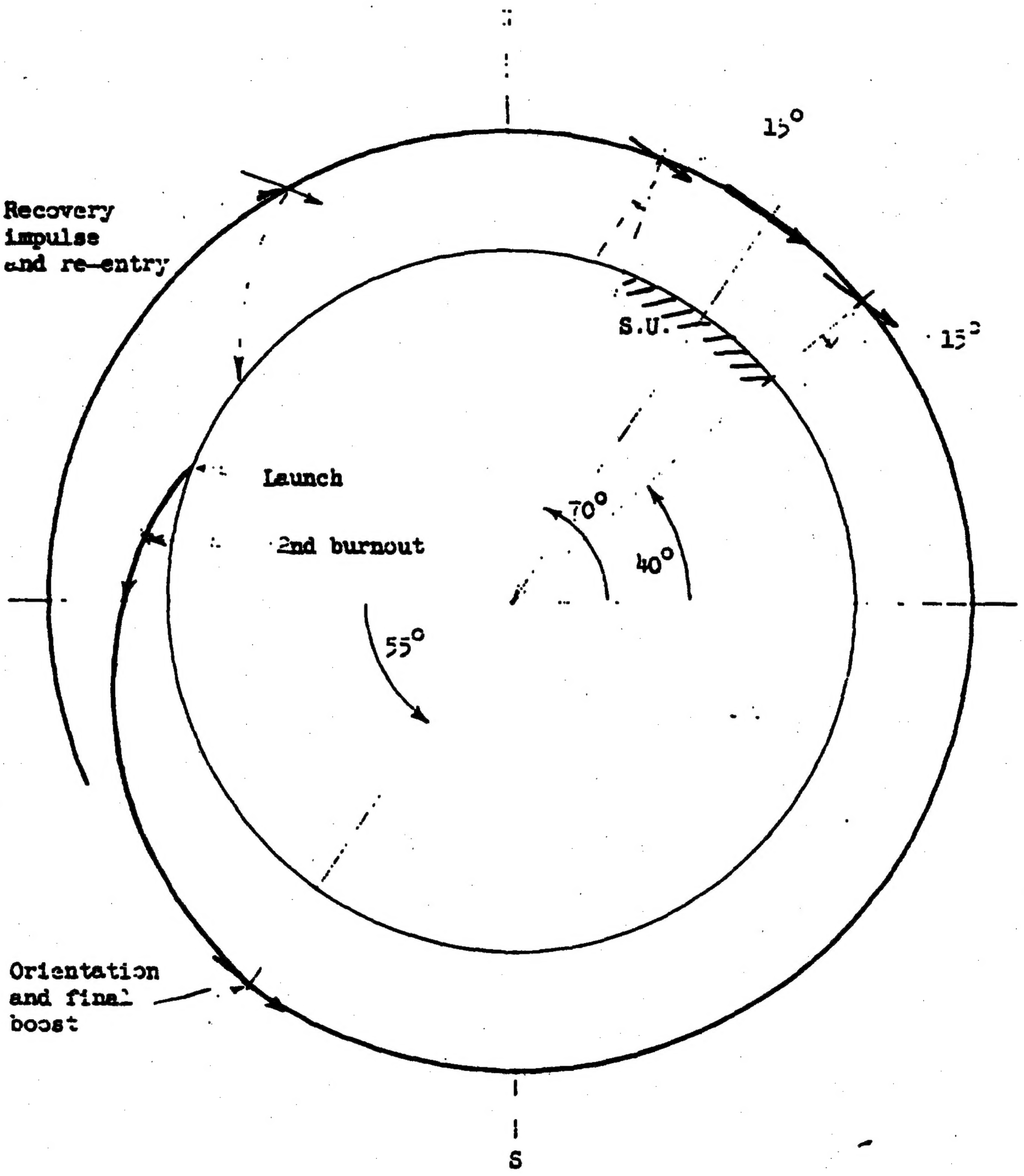

Fig. 2 Trajectory and Payload Attitude

job because of image blurring, the lack of sharpness, the lack of definition, and hence the lack of information-gathering capacity. This first impression is not entirely erroneous. It is difficult to take pictures from an object moving at high speed—but not impossible. It can be done if the image motion during exposure is kept as small as possible, consistent with the requirements for definition.

This satellite reconnaissance system is not intended to get microscopic resolution at, say, levels of 100 lines per millimeter. The goal, believed to be fairly easily attainable, is a modest 40 lines per mm of film resolution. This compares with certain specialized reconnaissance systems now in use.

A statistic commonly used in describing aerial reconnaissance systems is ground resolution. Ground resolution is simply the ground dimension that corresponds to one line of resolution in a focal plane. In this case a 12-in. focal-length lens and 40 lines per mm are being considered. Thus the width of a ground element produced or projected back on the ground through the lens system is 1/40 mm as seen from a distance of 12 in. or 300 mm. For the design altitude we have in mind here, the resolution is about 60 ft.

The effective design shutter speed for this camera is 1/4000 second. This speed is obtained by properly designing the slit described earlier, in conjunction with the film speed and rate of scan, or vehicle rotation. This exposure speed is consistent with the choice of film emulsion—called Plus-X Aerorecon—and the choice of lens speed, f/3.5. At the design altitude, about 6 ft of forward motion are produced during the exposure time of 1/4000 sec while the vehicle is moving at 25,000 ft/sec. This is 1/10 of the basic 60-ft resolution element, and can be tolerated, in fact ignored, for purposes of photo interpretation.

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This extremely fast exposure time makes it possible to ignore forward image motion; it also makes it possible to ignore altitude changes, probable angular displacements, velocity variations, and substantial variations in film rate.

3. THE ORBIT

A polar orbit is preferred, with a firing south from Patrick AFB or from Camp Cooke. A design altitude acceptable to the camera is 180±35 miles. Variations in altitude greater than 70 miles would not only affect scale but result in changes in the orbital period making it difficult to regulate camera operations with pre-set timing. If the satellite went much above 200 miles the braking rocket propellant weight would have to be increased and ground resolution would be degraded. If lower altitudes were used the satellite would encounter undesirable aerodynamic forces.

The weight of the camera and film installation is about 80 pounds. A total payload weight of 300 pounds has been selected, leaving about 220 pounds for payload structural components, re-entry coating, braking-rocket propellants, batteries to operate the film mechanism, beacon and transponder, and associated gear necessary to operate the camera and recover the package. It might be noted at this point that the power requirement for the camera is conservatively estimated at 100 watt-hours, which can be provided by a few pounds of batteries. Table I summarizes the payload-stage weights.

With respect to total time in orbit, a 1-day operation is envisaged. In one day the satellite will make about 16 revolutions around the earth, six or seven of which would occur over the Soviet Union. The camera carries a 500-foot film load, which will permit 300 exposures at a film speed of about 2½ inches per second. The payload rotates at about 20 revolutions

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Table 1

Payload Stage Weight Summary (lb)

Group A -	Photographic Installation		80
	Camera	38	
	Film	10	
	Environment	7	
	Altitude Sensor	10	
	Miscellaneous	15	
Group B -	Structure		110
	Shell	30	
	Fiberglas	80	
Group C -	Recovery System		110
	Impulse Rocket	85	
	Tracking Beacon	16	
	Recovery Beacon	9	

per minute, with the camera timed to make an exposure every third revolution.

Each exposure will produce a picture covering some 10,000 square miles on the ground. Each pass over the Soviet Union will cover about 3/4 million square miles on the ground, or nearly half the total land area of the Soviet Union. Figure 3 is a schematic representation of a 1-day operation.

The booster combination proposed for the early reconnaissance satellite is the Thor IRBM and the second stage of Vanguard, with a small solid rocket, similar to the third stage of Vanguard, to provide a final orbital increment. The propulsion is thus provided by a liquid-liquid-solid combination. Table 2 is a summary of vehicle weights.

From a preliminary structural investigation it appears that the Thor airframe and its major components need not be modified for the satellite mission. The Thor autopilot and control system can be used for first-stage guidance, although there is some possibility that this system would require some modification to offset the heavier load on the nose of the Thor and the increased loads during the ascent trajectory. For the satellite mission, the Thor inertial guidance system will not be required.

The basic airframe of the Vanguard second stage need not be modified for this application, with the exception of the aft interconnect structure, which will have to be designed to mate the 32-in. diameter Vanguard with the [illegible]-in. diameter Thor nose cone. The guidance system of the second-stage Vanguard would be used in conjunction with G.E. (107A) components.

The size of the third stage has not been optimized. However, the Vanguard third stage is characteristic, in concept at least, of the type

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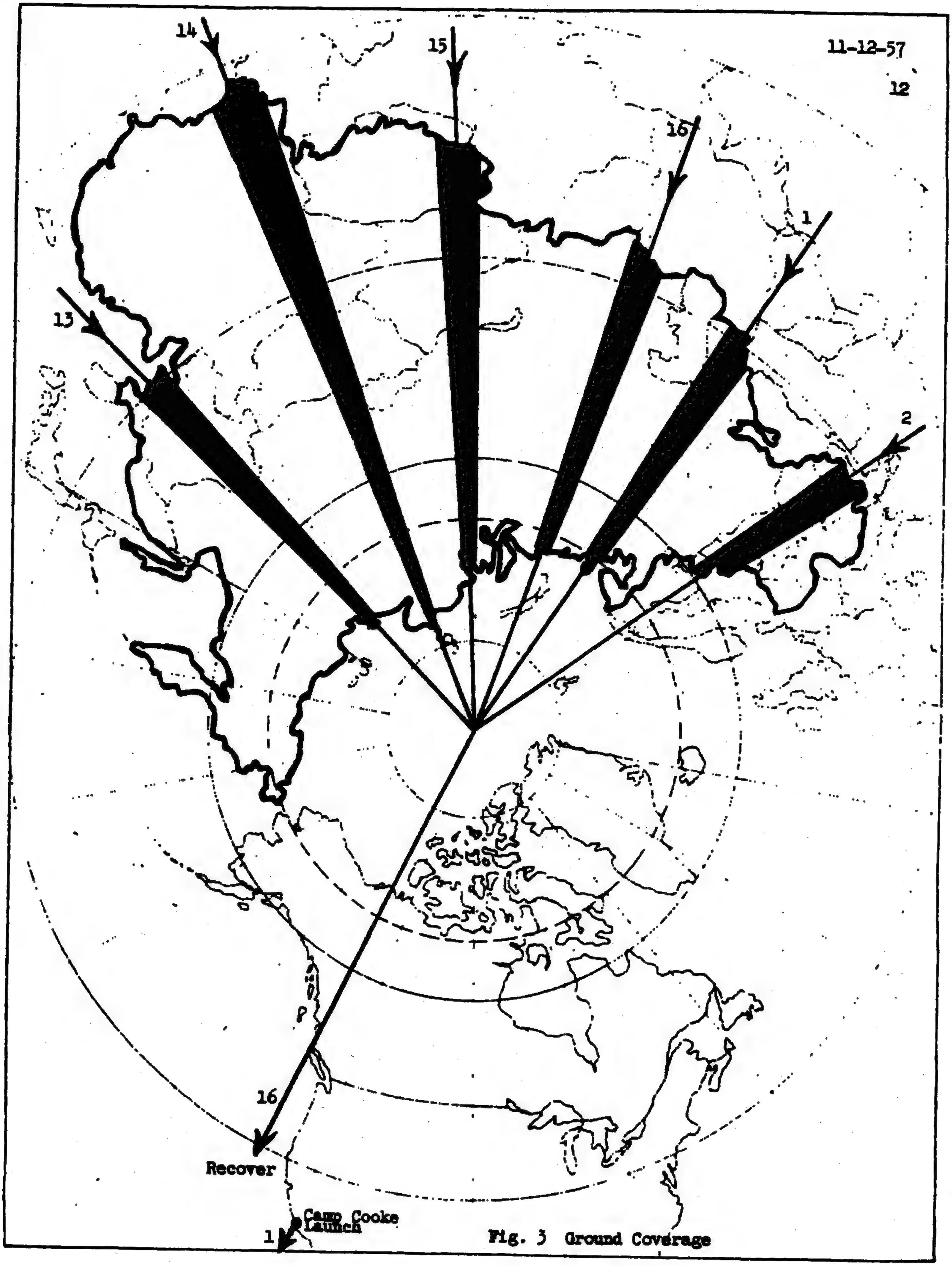

Fig. 3 Ground Coverage

Table 2

Vehicle Weight Summary

Orbital payload	300 lbs
Third stage (solid)	375 lbs
Second stage (Vanguard 2nd)	4,905 lbs
Initial stage (Thor)	110,910 lbs

of solid-propellant rocket meeting the requirements for the satellite under discussion.

The payload-stage configuration chosen for this case is a double conical shape with a maximum diameter of 35 inches (see Fig. 1b). A symmetrical body was chosen because of the desirability of minimizing possible aerodynamic lift forces at the relatively low orbital altitude. Skin material is assumed to be 0.050 magnesium alloy coated with a layer of Fiberglas-plastic combination on the forward end for heat protection. The payload stage includes a braking rocket using about 70 lb of propellants.

A typical ascent trajectory is shown in Fig. 4. This powered-ascent trajectory is effected by the combination of the Thor booster, with first-stage guidance preprogrammed for the autopilot, and the second-stage Vanguard using its own guidance in conjunction with the G.E. radio system. The burnout velocity attained by the two boosters is about 24,000 ft/sec, with a final-stage weight of about 350 lb.

After a period of coast to a design altitude of about 200 miles, the second stage, containing the spin-up and separation mechanism for the third stage, orients and spins the third stage in preparation for the final velocity increment. The orientation, produced by orientation jets in the second stage, is to a pitch attitude such that the vehicle is parallel to the earth's surface at 35 degrees north (or south) latitude. After orientation, and before the third stage fires, the third stage and the payload are spun around their roll axis to the angular velocity needed to stabilize the vehicle and provide the proper scan rate for the camera.

The firing of the third stage separates it from the second stage and imparts the final orbital velocity increment of 1300 ft/sec required to attain the proper altitude (about 160 mi) over the Soviet Union. At third-stage burnout, a small retro-rocket is fired, separating the payload and

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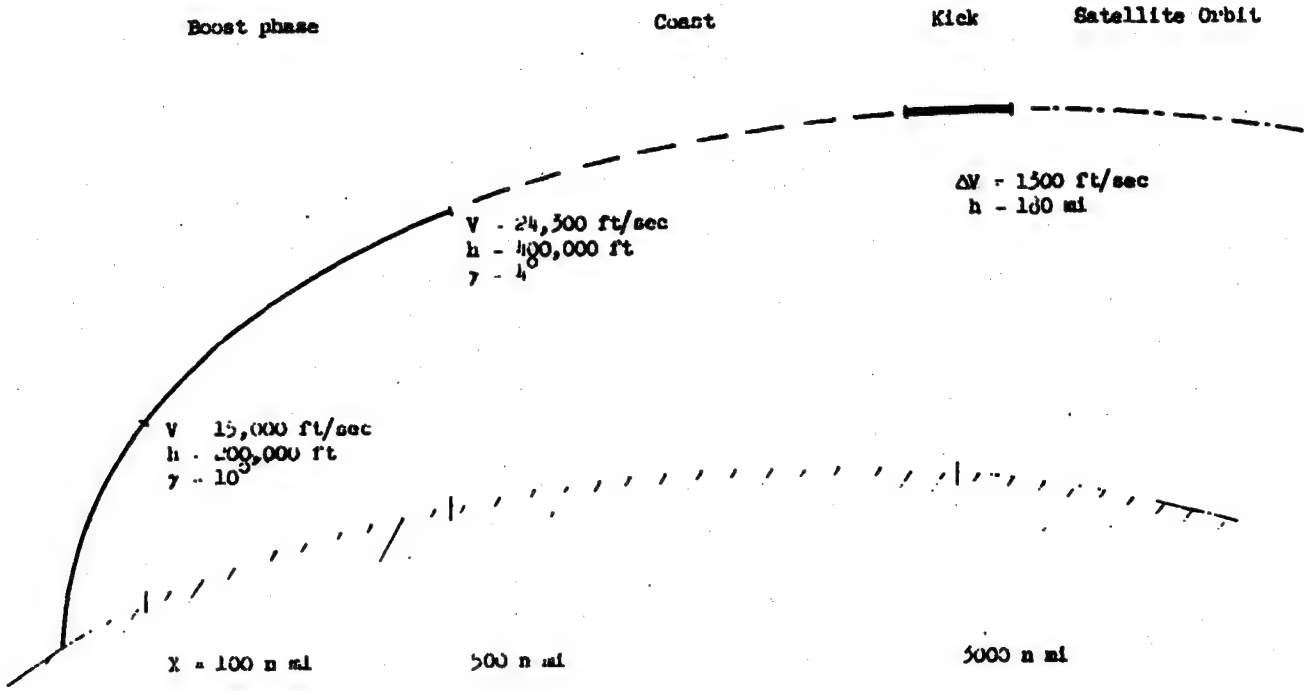

Fig. 4 Ascent Trajectory

leaving it, properly oriented and spin-stabilized, free in space.

4. Tracking and Recovery

Tracking will be required for essentially three reasons: to determine the orbit accurately enough for coordination of photographic data; to trigger the braking rocket at the proper time for the descent; and to establish the descent path so that the impact point can be located.

The number of trackers required and the spacing between them is dictated partly by the guidance accuracy. To insure against guidance inaccuracies in launching, it is proposed that two or three trackers be used in an arrangement which places them generally with about a 200-mi separation on a line normal to the orbit.

A second factor that must be considered in determining the number and spacing of trackers is the deterioration of tracking accuracy at low angles above the horizon. It is highly important that the satellite pass close enough to at least one station so that sufficient tracking data can be obtained at angles of elevation greater than about 20 degrees. For a nominal satellite altitude of 180 mi, this requires that the satellite pass within roughly 5 degrees of the station, or within a ground range of about 350 mi. Again, two or three trackers at intervals of 200 mi normal to the orbit are dictated.

Because the satellite is to be placed on a polar orbit, these objectives can be met by a small number of trackers near one of the poles. It seems advisable to locate the tracking stations, say three of them, at a high northern latitude such as in Alaska or Canada. Spacing should be about 200 mi in longitude.

Tracking data would be in the form of two angles and a range to permit orbit prediction. The use of range information considerably relaxes the requirement for angular accuracy. To obtain range, a transponder in the satellite is required.

Descent from orbit is achieved by the command firing of a braking rocket in the satellite. Assume that the satellite is coming over the pole, that it is picked up by our trackers in the north, and that an impact point in the Pacific is desired. The braking rocket is then fired forward and upward, imparting a downward and backward velocity impulse superimposed on the orbital velocity. The resulting velocity vector points downward, so that the vehicle is effectively in a ballistic trajectory comparable to the 'low-angle', i.e., lower-than-optimum, path of a long-range ballistic missile.

Tracking of the vehicle immediately after the beginning of descent establishes a predicted vacuum path. This, together with predicted atmospheric effects, makes it possible to predict the approximate impact area. The vehicle is protected against re-entry heating by a coating of suitable vaporizing material; 80 lbs of Fiberglas-reinforced plastic, such as that used on advanced designs of the ICBM nose cone and on the Jupiter nose cone, are suggested. Impact survival of the casing, film load, batteries, and beacon is made feasible by the proper selection and arrangement of structural components. Search aircraft are used to find and recover the payload. This means that the radio beacon must operate after water impact, and possibly that some type of dye marker should be released upon impact.

5. INTELLIGENCE PAYOFFS

Photographs produced by the system just described should enable us to do a useful reconnaissance job at Level A, over areas measuring millions of square miles. The scales and resolution that will be possible are comparable to those obtained with certain kinds of photographic mapping equipment standard on Air Force reconnaissance aircraft today. They will make it possible to identify major railroads, highways, and canals. Urban centers, industrial areas, airfields, naval facilities, seaport areas, and the like can be seen. Very likely, defense missile sites of the sort found around the Moscow area will also be identifiable. Thus, with repeated surveillance, it will be possible to find new major installations, perhaps to learn something about patterns of use of Soviet ICBM systems, and certainly to obtain clues for the direction of other, higher-resolution systems that can go back and take another look.

5. GROWTH POTENTIAL

Clearly, the major emphasis of this recommendation is on the easiest and earliest recoverable photographic satellite system. This version, the 12-in., f/3.5 camera using 500 ft of 5-in. film, and based on the Thor booster, is seen as the first of a series of such cameras and systems. This system is capable of photography at Reconnaissance Level A in adequate detail. As the system is proved out, as confidence is gained in satellite operations, and as environmental constraints and intelligence problems become better understood, more advanced systems can be constructed. The first system would be followed by a 36-in. focal-length system, using 1500 ft of 9-in. film. At this time it appears that this system can also be put on orbit using a Thor-type booster, with a maximum payload weight of about 300 lb.

This second system should provide reconnaissance at Level B, giving adequate detail over areas of hundreds of thousands of square miles. Eventually this system could evolve into one using a 10-ft focal-length lens and about 2500 ft of 18-in. film, based no longer on the Thor but on the

Atlas booster, and doing a reconnaissance job at Level C, or over specific point objectives. The time phasing of the several projects should be about as follows: availability of the 12-in. system one year from date of contract; availability of the 36-in. system in 18 months; and availability of the 10-ft system 36 months after the start of the program (Fig. 5).

To conclude, it is believed that the type of system proposed here will work, can be available quickly, and will fill a vital military reconnaissance need both in the near and in the distant future.

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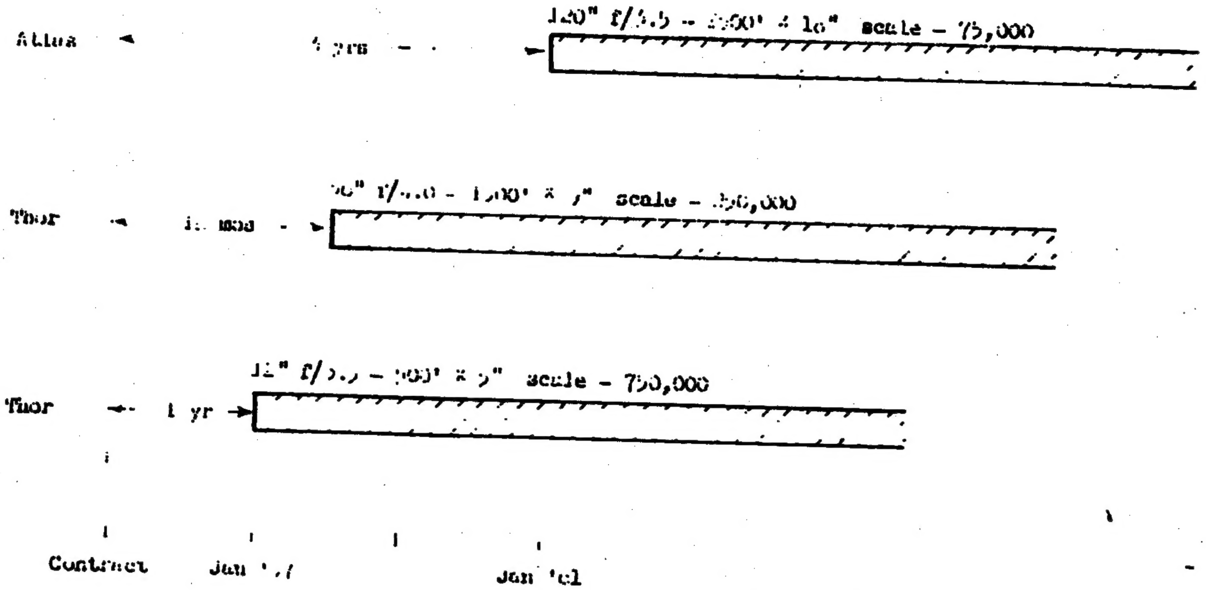

Fig. 5 Growth Potential

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DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON 25, D.C.

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25 November 1957

MEMORANDUM FOR MAJOR GENERAL SWOFFORD, AFDRD

SUBJECT: RAND Recommendation "An Earlier Reconnaissance Satellite System (S)

General Putt has reviewed the attached report and commented as follows:

> "General Swofford:
>
> "This is one we should start immediately. Request DRD make recommendations to me as to how we might proceed. I'd like DRD ideas before any contact is made with ARDC. Please see me re this.
> DLP"

Incl
Rand Rpt on
above subj.

FRED W. LUOTERHAND
Lt Colonel, USAF
Assistant Executive
DCS/Development

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